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Physics Informed State Estimation Technology for Battery Storage System

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The authors are developing advanced control technologies for battery management systems to enhance the value of electric vehicles and contribute to regional carbon neutrality and power grid stability. Battery management systems play a crucial role in extending battery life and enabling efficient energy utilization by optimally controlling the power of storage batteries. Accurately estimating the battery state is critical to extending its usable range while accounting for degradation. This paper reports a state estimation technique that incorporates battery physical model information into an equivalent circuit model, enabling high-precision and robust estimation of internal state variables even under degraded conditions.

This paper employs the equivalent circuit model shown in Fig. 1, in which the fast and slow components of the diffusion process are represented by a two-stage parallel RC circuit. The time constant of the diffusion process are defined by Equations (1). Where R_d, C_d, D and L_{Dmax} represent the diffusion resistance, diffusion capacitance, diffusion coefficient and inter-electrode distance, respectively. The battery degradation rate induced by environmental variations is proportional to the degradation rate predicted by the Arrhenius law. By fitting the physical parameters using the proportionality constant $1/D$ in Equation (1) as an indicator of the degradation rate, the degradation characteristics can be incorporated into the equivalent circuit model. These analytical results enable the identification of diffusion resistance while accounting for degradation rates and temperature dependence. Fig. 2 shows a comparison between measured voltage response to a rectangular wave input and the corresponding response calculated using the 2RC equivalent circuit model. The two results show good agreement, confirming the validity of representing the concentration-diffusion polarization voltage using the 2RC equivalent circuit model.

The current integration method is widely adopted as a representative approach to SOC estimation. As battery degradation progresses, the full-charge capacity decreases. Therefore, over-discharge or over-charge will accelerate degradation, if capacity parameters are not updated as appropriate. This paper employs parallel independent linear Kalman filters for SOC and SOH estimation to avoid complex estimation procedures arising from model characteristics, thereby improving estimation accuracy and robustness against capacity degradation.

This paper considers a 50Ah ternary lithium-ion battery cell as the target vehicle battery cell for estimation study. The accuracy of the state estimation model constructed is verified. Charging and discharging data obtained during WLTC driving cycles were used as input to the state estimation model. The estimation results are presented in Fig. 3. Both SOC and SOH closely follow the true values throughout the entire driving range, and the SOC estimation accuracy within ±3%.

$$T_{sat} = \left(\frac{L_{Dmax}^2}{\pi}\right)\left(\frac{1}{D}\right) \simeq 5R_dC_d \quad (1)$$

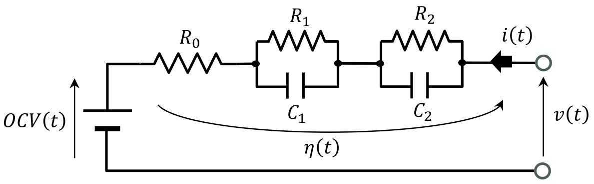

Fig.1 Equivalent circuit model

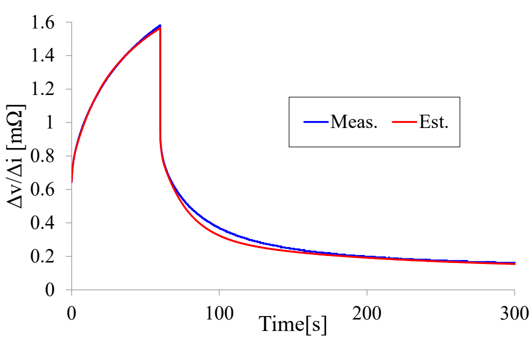

Fig.2 Comparison result

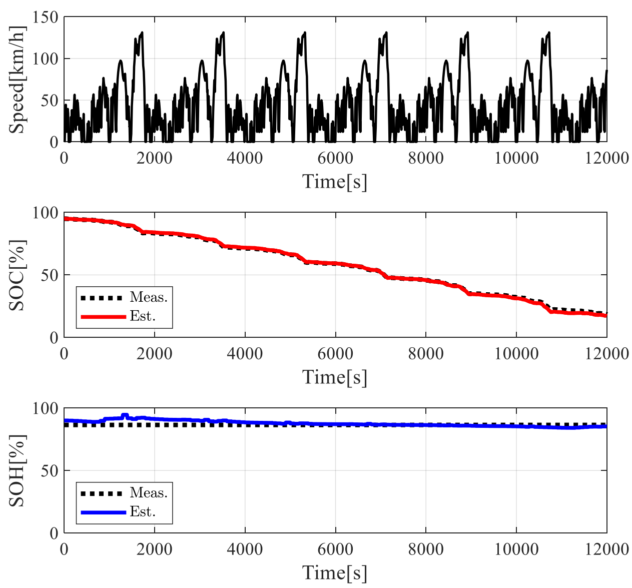

Fig.3 Estimation result of Lithium-ion battery states

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